73rd MORSS CD Cover Page

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OPTIMAL RESOURCE ALLOCATION
and
MULTI-DIMENSIONAL MCM THEORY

John C. Hyland, PhD

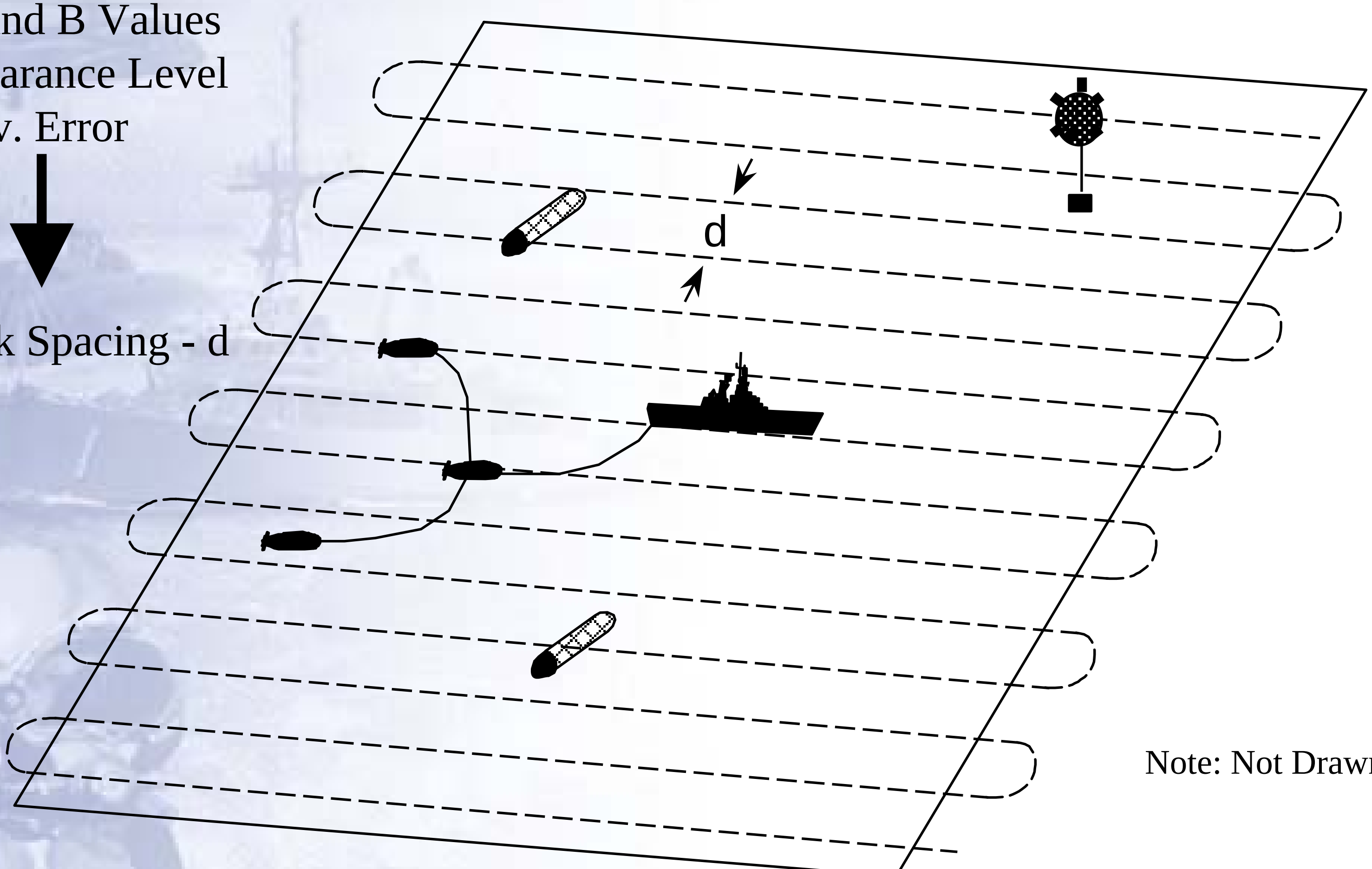
Cheryl M. Smith, PhD

Automated Decision Processing Branch

Traditional MCM Analysis

- Bottom Type
- A and B Values
- Clearance Level
- Nav. Error

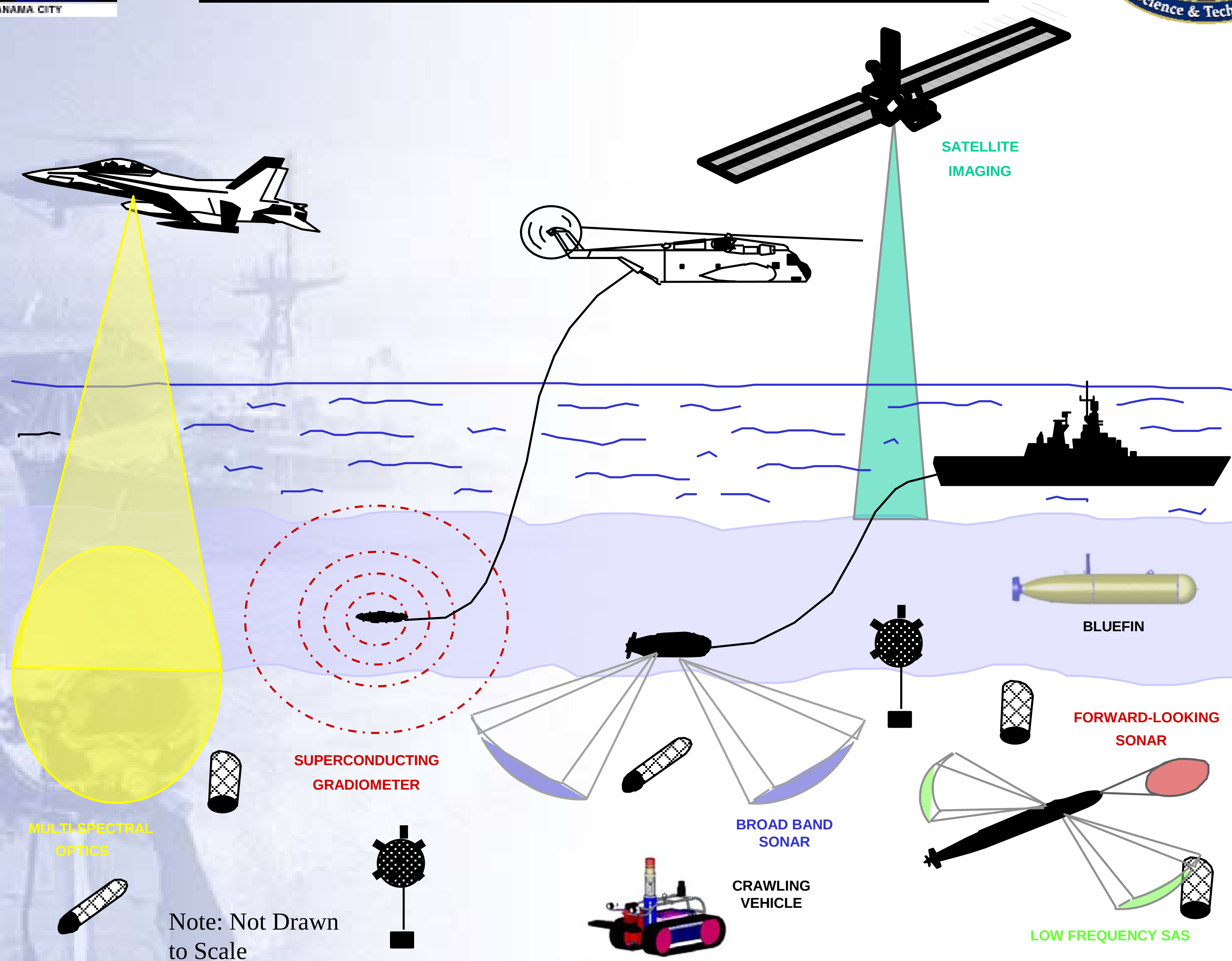
Track Spacing - d



Note: Not Drawn to Scale

1960's MCM SCENARIO (Reber)

Current MCM Scenario



Current Opportunities

Asset Allocation

- Which platforms should be assigned to the mission areas?
- Which sensors should be assigned to the platforms?

Multi-Dimensional Tactical Analysis

- What factors should the mathematical model include?
- Over what factors do we have sensor performance data?

Optimization

- What is the optimum platform trajectory?
- What are the optimum joint platform trajectories?
- What is the optimum prosecution sequence?
- When is the optimum time to reload?
- Can multi-platform performance (joint performance) be calculated?
- Should we use Monte Carlo or analytical methods?

Mine Avoidance

- What is the minimum risk of passing through a potentially mined area?
- How do we go through the minefield with minimum risk?

Minefield Planning and Analysis

- Where should we put the mines to get the best performance?
- How many mines?
- What type of mines?

Optimization Techniques For Mine Warfare Decision Making

- Search Tree Algorithms
- Dynamic Programming
- Markov Process Modeling
- Monte Carlo Simulations
- Incremental Optimization
- Combinatorial Optimization
- Bayesian Strategy Analysis
- Multidimensional /Multivariate Probabilistic Modeling

Analytical vs. Monte Carlo Analysis

Mission Factors

Uncontrollable Factors

- Environment
- Target Distribution
- Target Types
- Sensor Performance
- Intelligence Data
- Mission Constraints
- etc.

Controllable Factors

- Platform Selection
- Sensor Selection
- Asset Allocation
- Platform Trajectories
- Sensor Fusion
- Multi-Sensor Performance
- Engagement Area
- etc.

MODEL

Analytical Results

Advantages:

- **Computationally Fast**
- **Exact Solutions**

Statistical Parameters

Monte Carlo Results

Advantages:

- **Complex**
- **Non-Linear Models**

Sample Estimates

MOEs

- Pd
- Pc
- Pn
- Pa
- Pi
- Risk
- Losses
- Time

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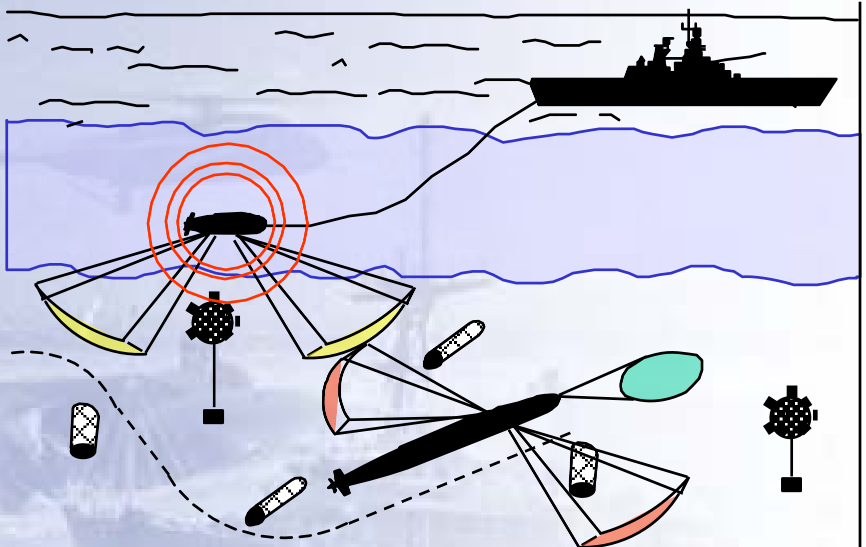
Multi-Dimensional Tactical Analysis



DISADVANTAGES:

- Planar Analysis Greatly Over Simplifies the Problem and Conceals Optimization Opportunities
- Analytical capability has not kept up with rapid pace of MCM sensor and platform R & D
- Not adequate for multi-sensor MCM systems
- Not adequate for multi-platform MCM systems
- Cannot determine MOP/MOE confidence intervals
- pd(y) curve modeled as a trapezoid
- Trapezoid parameters A and B not uniquely defined
- Can only accommodate Gaussian navigation error
- Can only accommodate uniform mine spatial distributions

PURPOSE:

- To modernize MCM theory and tactical analysis

CURRENT APPROACH:

- Approximates pd(y) curve by trapezoid of height B & width A
- Assumes Gaussian navigation error having known variance
- Implementation based upon retrieving data from tables as a function of A, B, variance, and clearance level

ADVANTAGES:

- Simple to Use
- Easily understood
- Works well when trapezoid is a good fit for the pd(y) curve

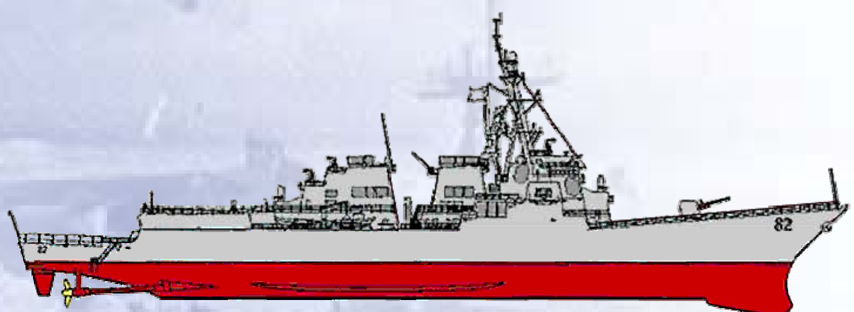
RESULTS:

- Developed a new joint multi-dimensional MCM theory (general search theory) that accommodates:
  - Generalized pd(y) curves and nav. error distributions
  - Multiple platforms with multiple sensors on each platform
  - Multi-Dimensional sensor performance curves
  - Estimators and confidence intervals for Pd
- Increased MCM mission performance with no added cost
- Developed a preliminary Pd optimization strategy (single platform)

FUTURE RESEARCH:

- Develop new MCM MOEs
- Develop tactics for single platform mission optimization
- Develop tactics for multi-platform mission optimization

Multi-Dimensional Analysis Example



Platform 1

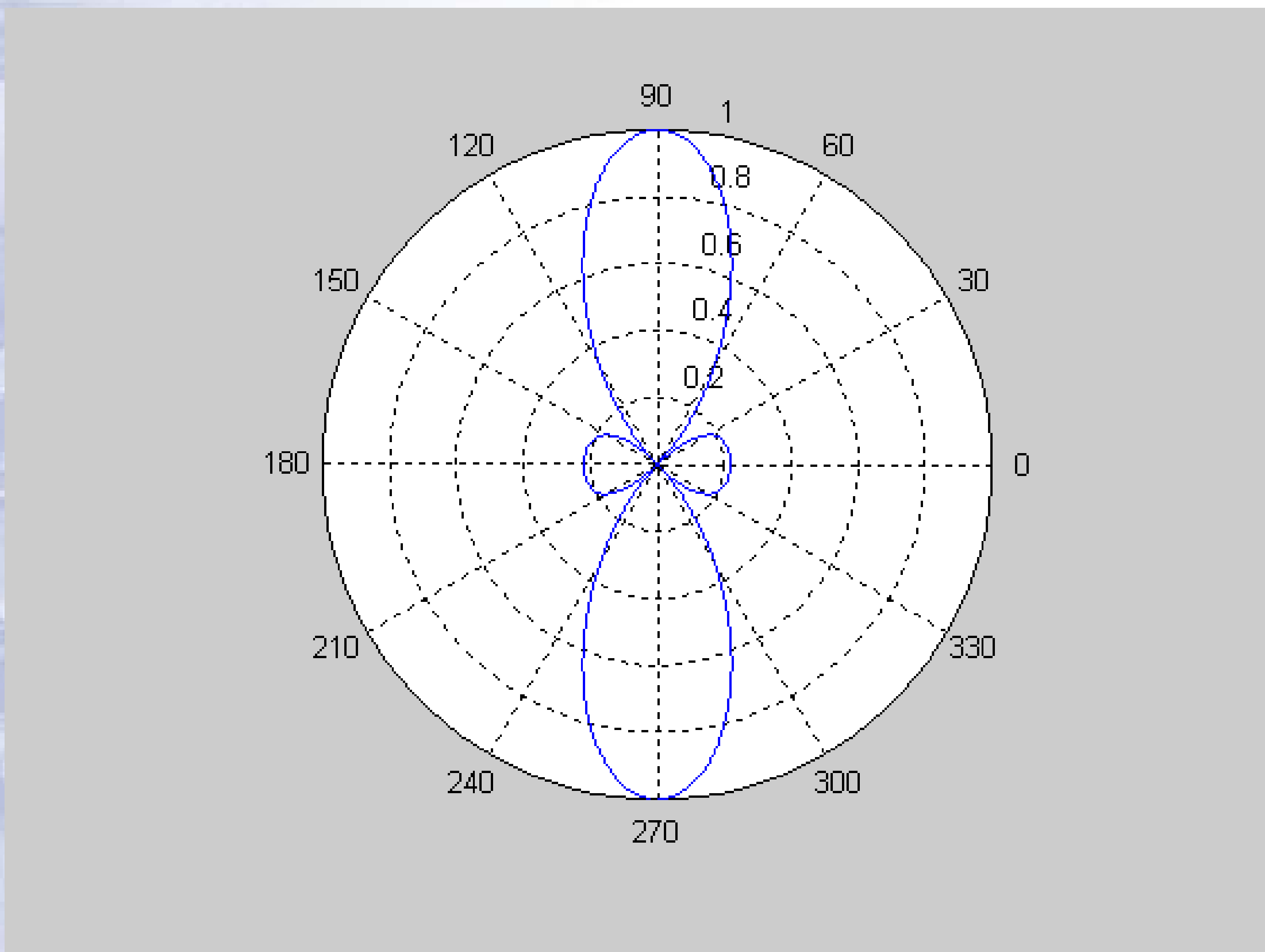
Platform 2

Example Problem:

- Two platforms are available
- Each platform has one sensor
- Each platform can cover the assigned mission area once
- Platforms will use traditional mow-the-lawn tracks

What coordinated track pattern will optimize mission results - parallel tracks or perpendicular tracks?

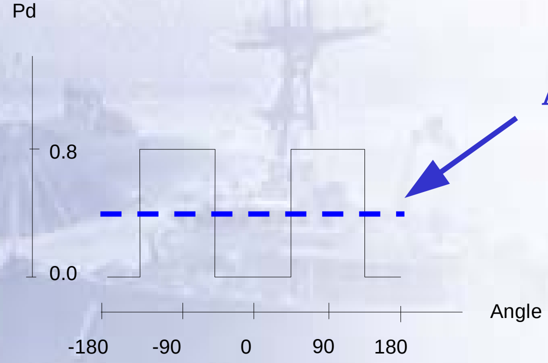
Hypothetical Target Strength vs. Aspect



Multi-Dimensional Analysis Example

Sensor 1

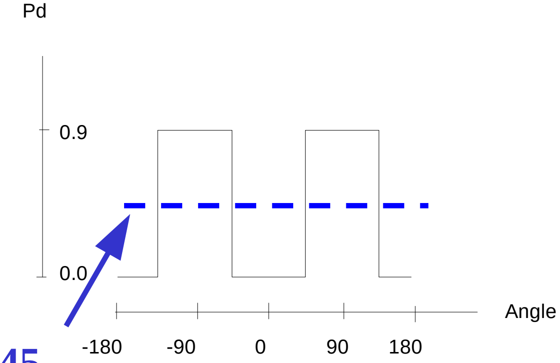
Pd vs. Angle



Average Pd1 = 0.40

Sensor 2

Pd vs. Angle



Average Pd2 = 0.45

- True Pd is Typically Angle-Dependent
- Traditional Tactical Analysis Uses Average Pd

Sensor 1: $-37.5 < x < 37.5$, $-62.5 < y < 62.5$, $-25.0 < z < 25$

Sensor 2: $-37.5 < x < 37.5$, $-62.5 < y < 62.5$, $-25.0 < z < 25$

Reber: P(At Least One) = $1 - [1-\int Pd1(a)p(a)\,da]\ [1-\int Pd2(a)\,p(a)\,da]$

Exact: P(At Least One) = $1 - \int \{[1-Pd1(a)]\ [1-Pd2(a)]\}\ p(a)\,da$

where p(a) = pdf of target as a function of angular orientation

Multi-Dimensional Analysis Example

TABLE 1. EXAMPLE SUMMARY			
Scenario	P(none)	P(at least once)	P(twice)
Parallel Tracks (Exact)	0.51	0.49	0.36
Perpendicular Tracks (Exact)	0.15	0.85	0.00
Reber Model (for both scenarios)	0.33	0.67	0.18

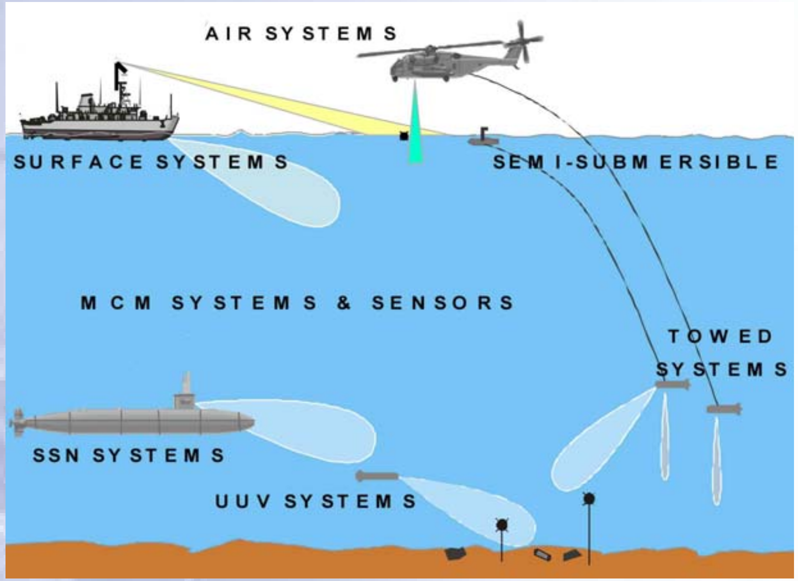
Why the Different Results?

Theoretical Model Assumptions have been Violated !-

- Once the First "Random" Track is Chosen, All Other Tracks are No Longer Random!

- Random Target Orientation Assumption is Invalid!

Optimal Asset Allocation



Objective:

Develop Real-Time Optimal Asset Allocation Capability for Assigning Assets to Pre-partitioned Areas

Payoff:

- Optimal Mission Performance
- Dynamic Re-Allocation
- Automated
- Near Real-Time

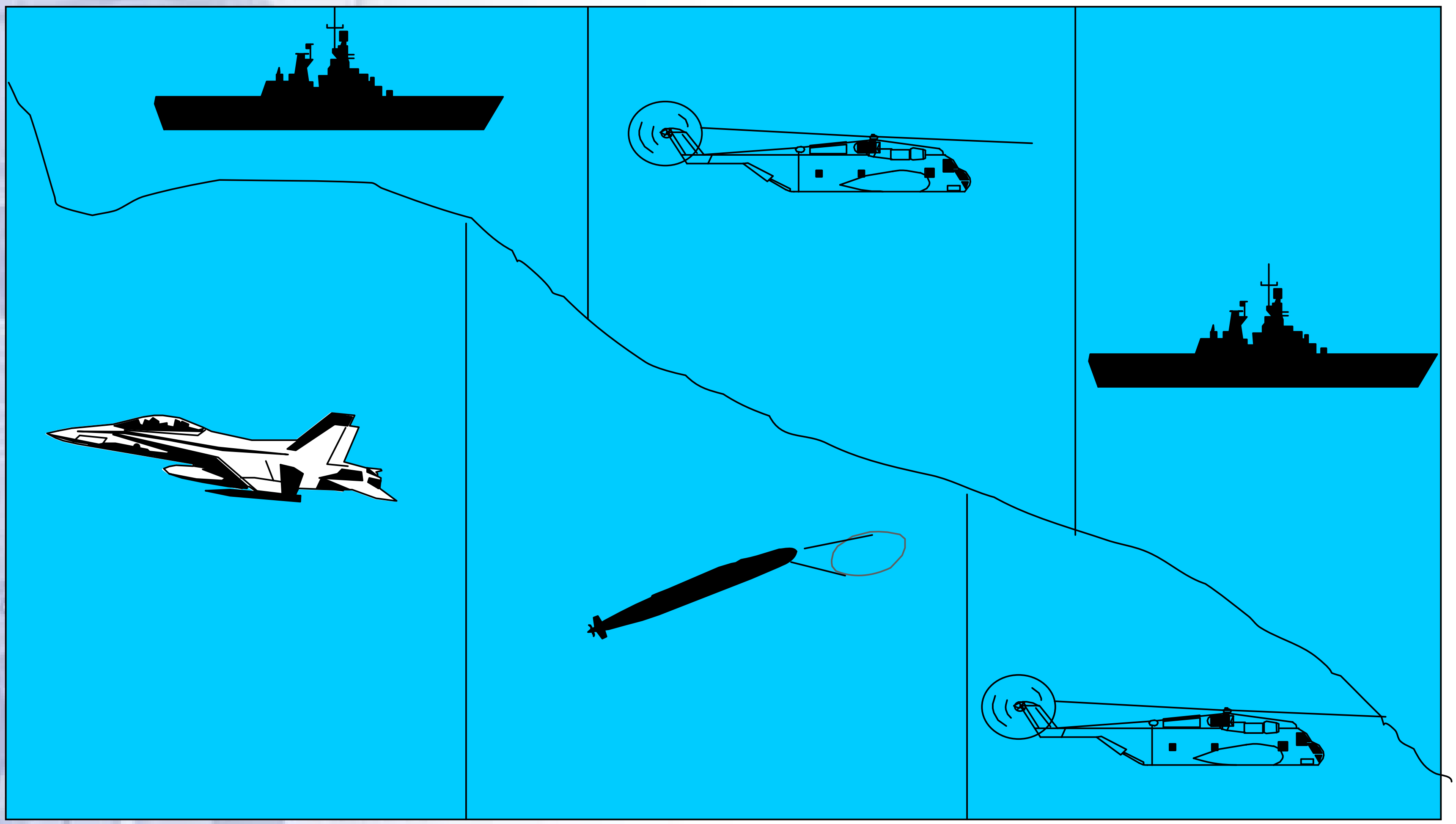
Resource Allocation Background:

- Done Manually
- Slow (6 hours to several days)
- Limited to Small No. of Assets
- Not Optimal
- Not Dynamic

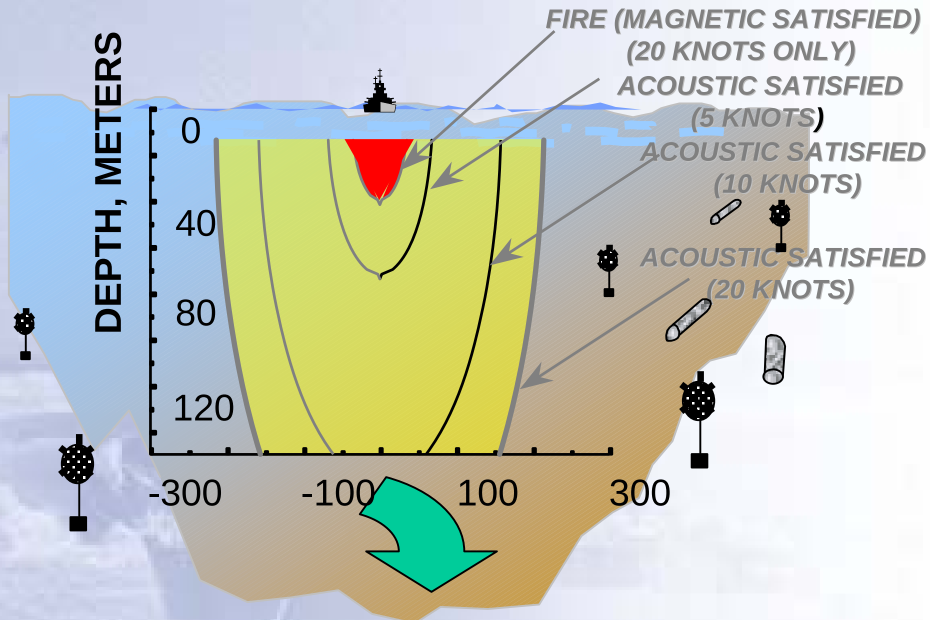
Technical Issues:

- Numerous constraints
  - Specialized Assets, Availability
  - Performance Differences
- What Objective Function to Use?
- Performances Not Known as a Function of Controllable Variables
- Minimal Effort Required

Manual Partitioning & Allocation



Minimum Risk Planning Tool



Objective:

Determine Minimum Risk Path Through a Minefield

Payoff:

- Reduced Risk
- Dynamic Path Re-Planning
- Provides Total Risk Calculation

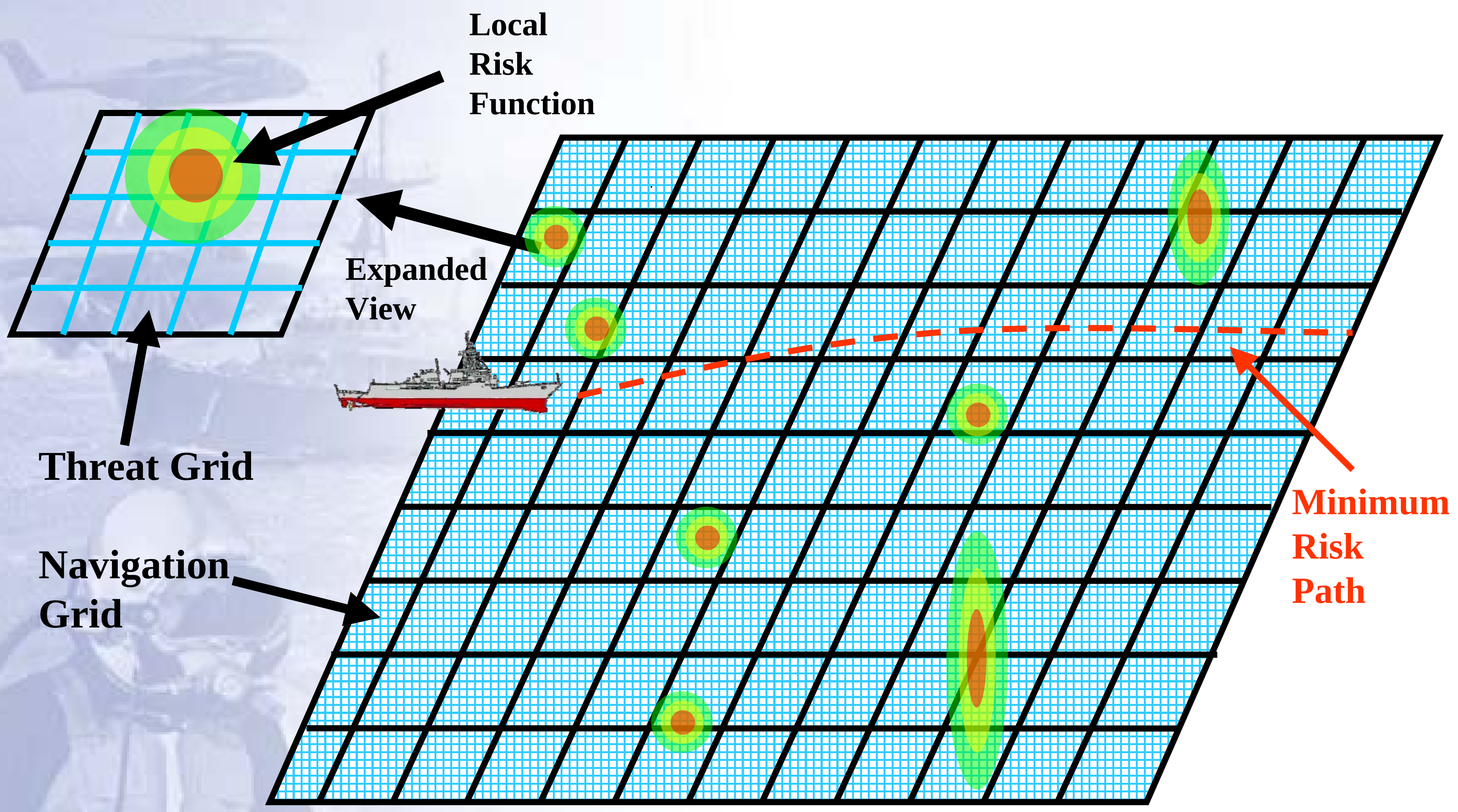
Technical Issues:

- Mine Position Errors
- Own-Ship Navigation Errors
- Multiple Coordinate Systems
- Turn & Speed Changes
- Environment & Topography
- Different Mine Types
- Undetected Mines
- Expected Damage Functions

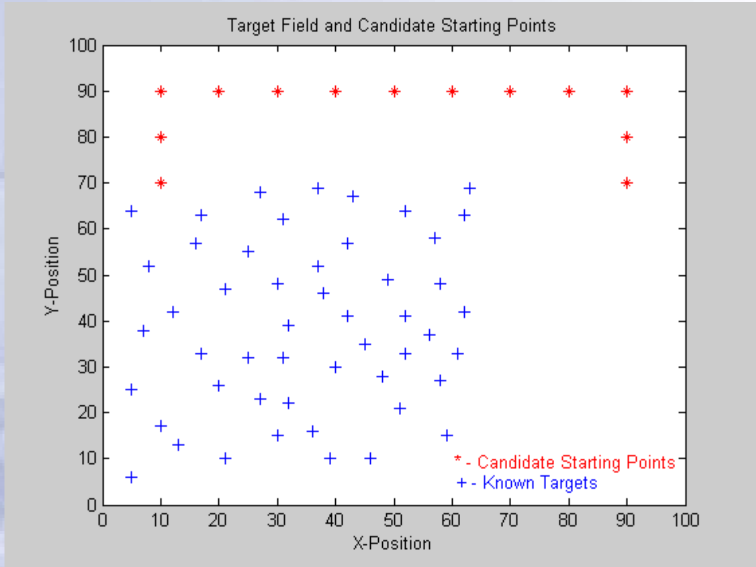
Approach:

- Utilize Navigation Voxels & Threat Sub-Voxels
- Map to Single Coordinate System
- Compute E{No. of Mines} for Each Threat Voxel
- Compute E{Risk} in Threat Voxels
- Use Dynamic Programming to Determine Minimum Risk Course

Minimum Risk Concept



Optimal Reload Strategies



Objective:

Develop an Optimal Reload Strategy for Search and Destroy Missions

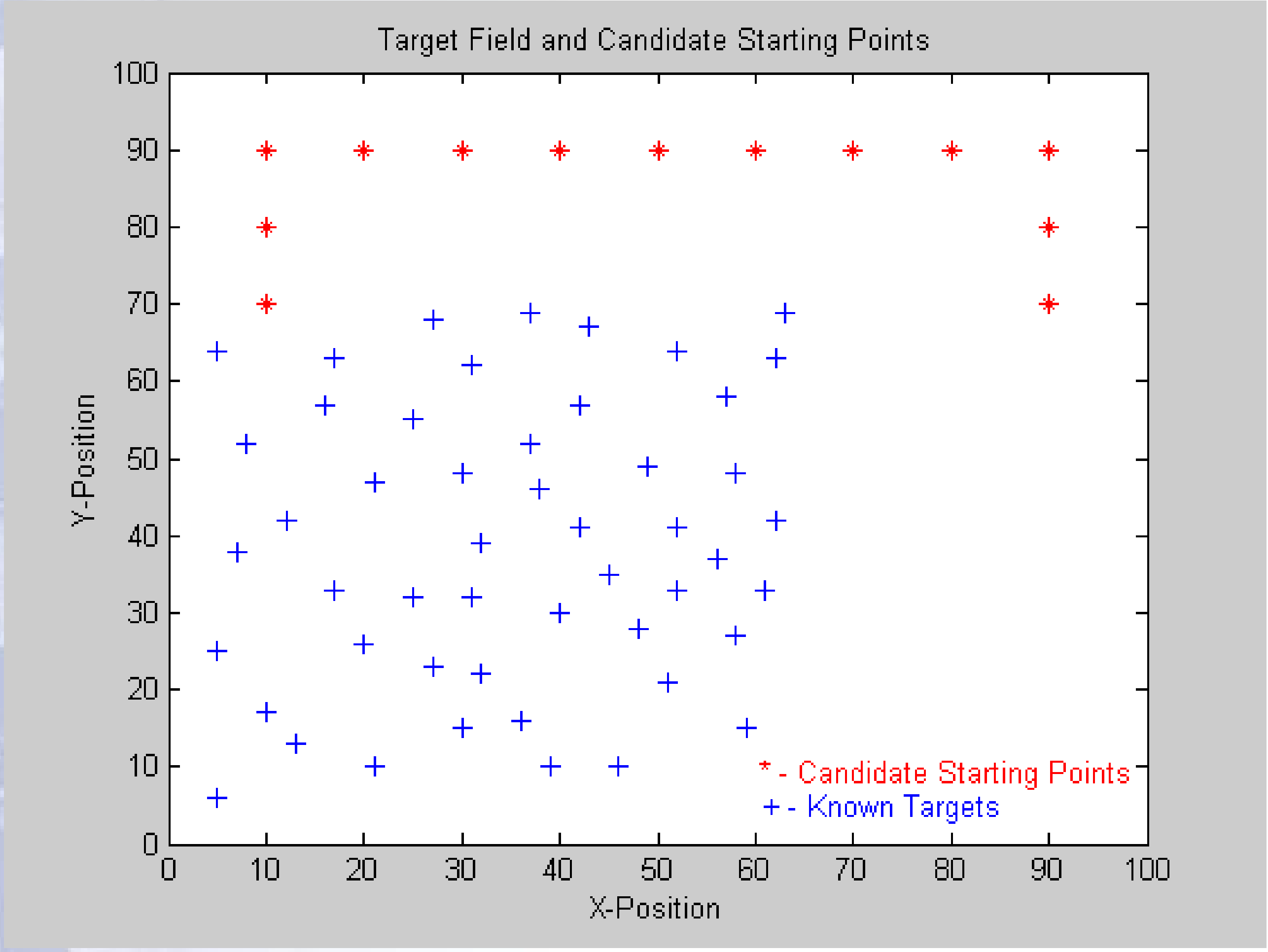
Problem Conditions:

- Given List of Potential Targets
- Each Target has Unique p(mine)
- Assume 100% Identification
- No Navigation Error
- Reload Decisions Conditioned on Pre-defined Reacquisition Order

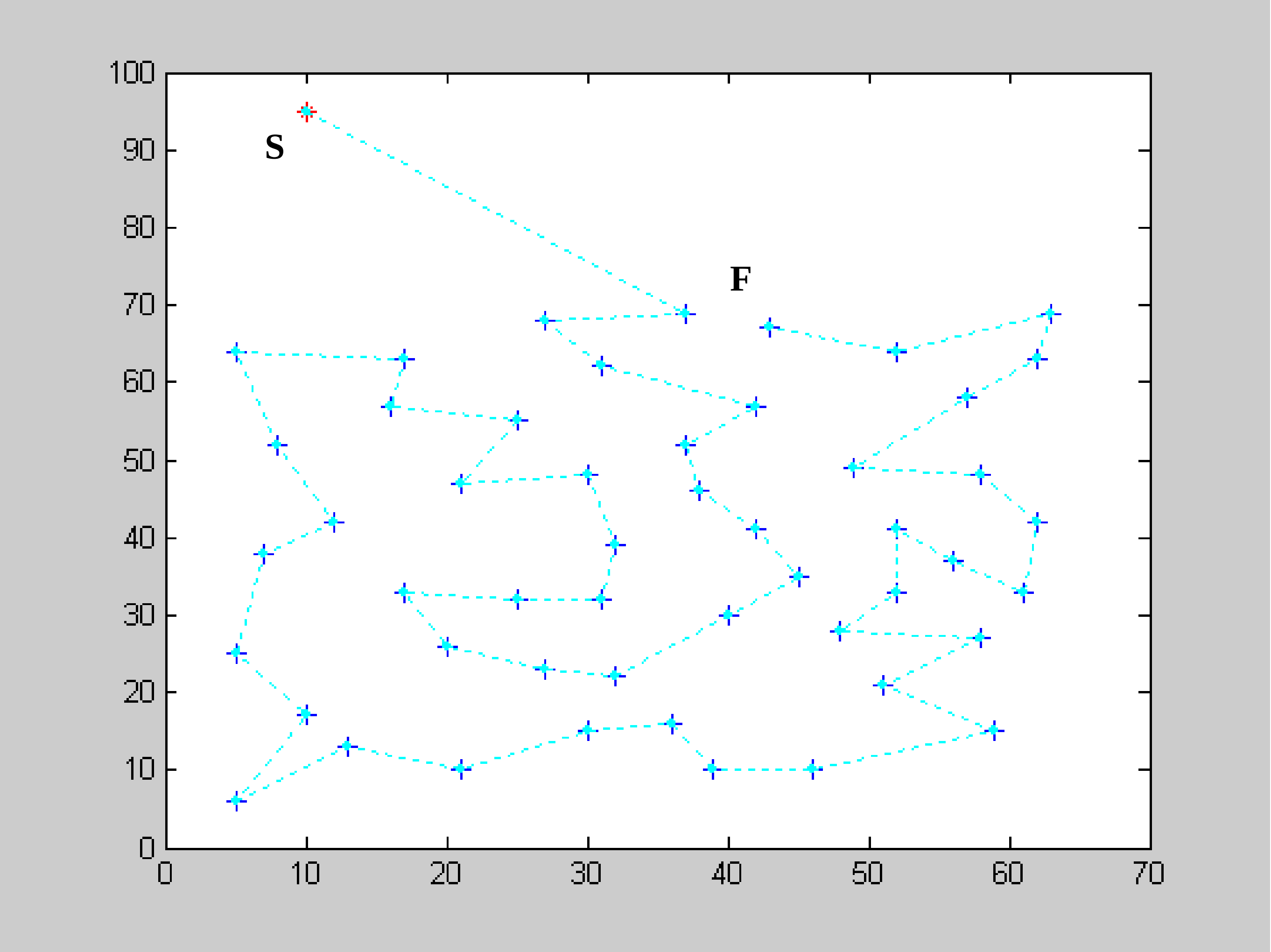
Results to Date:

- Developed Optimal Reload Strategy
- Added Sub-optimum Path Planner to Reload Strategy
- Demonstrated Algorithm and Path Planner in Matlab 6.1
- Identified Future Research

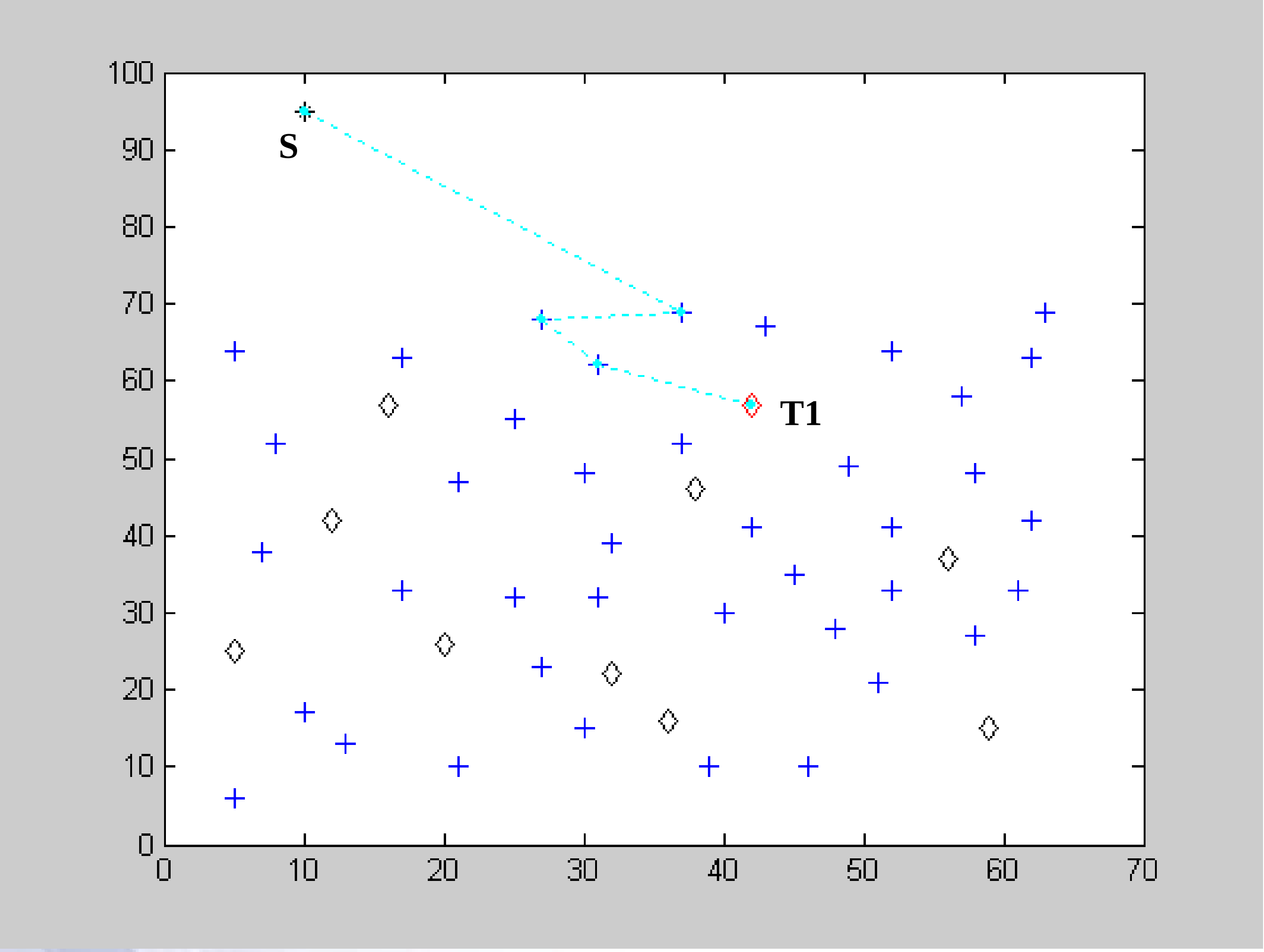
Target Field and Candidate Starting Points



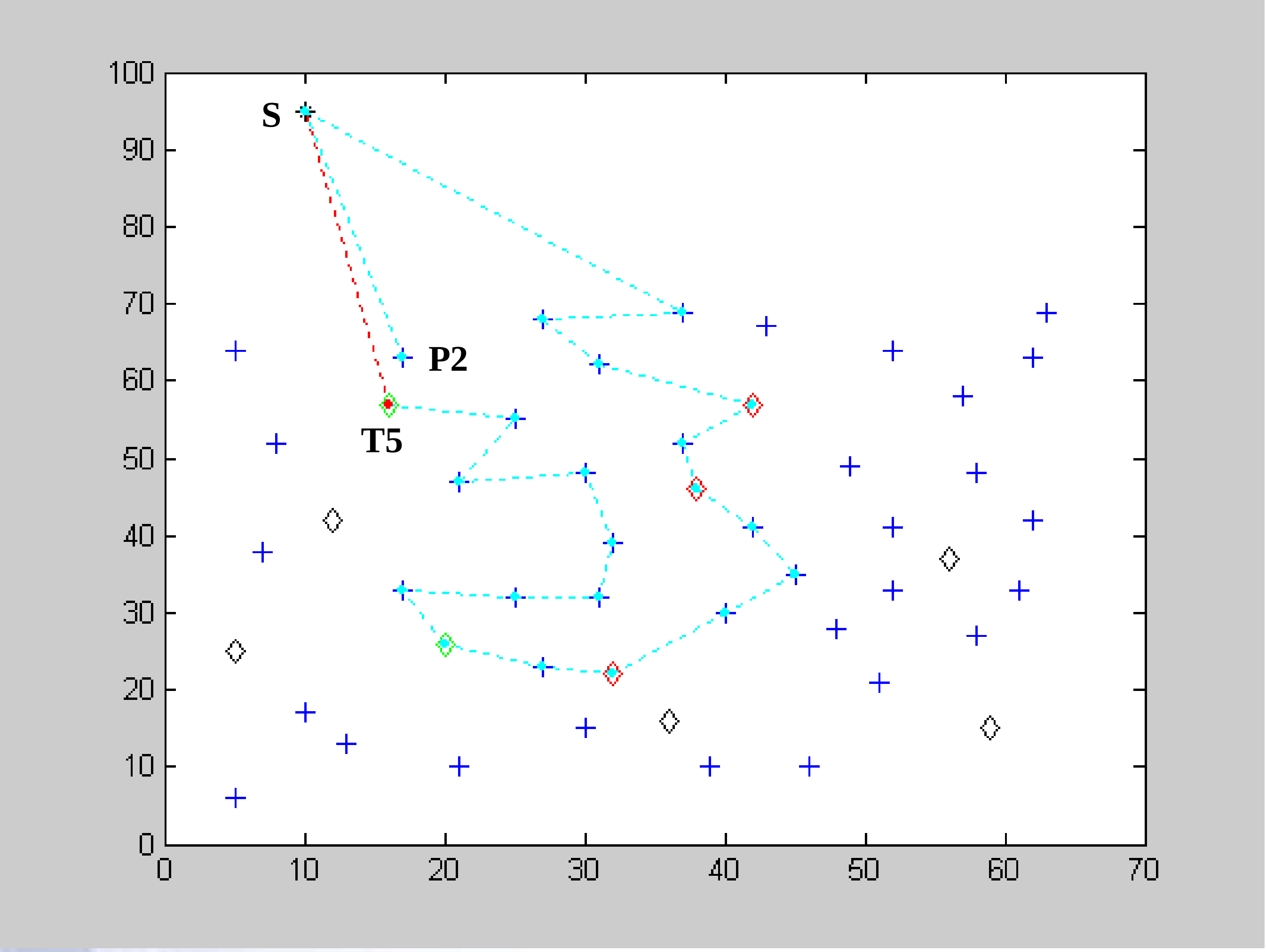
Sub-Optimal Path through Target Field



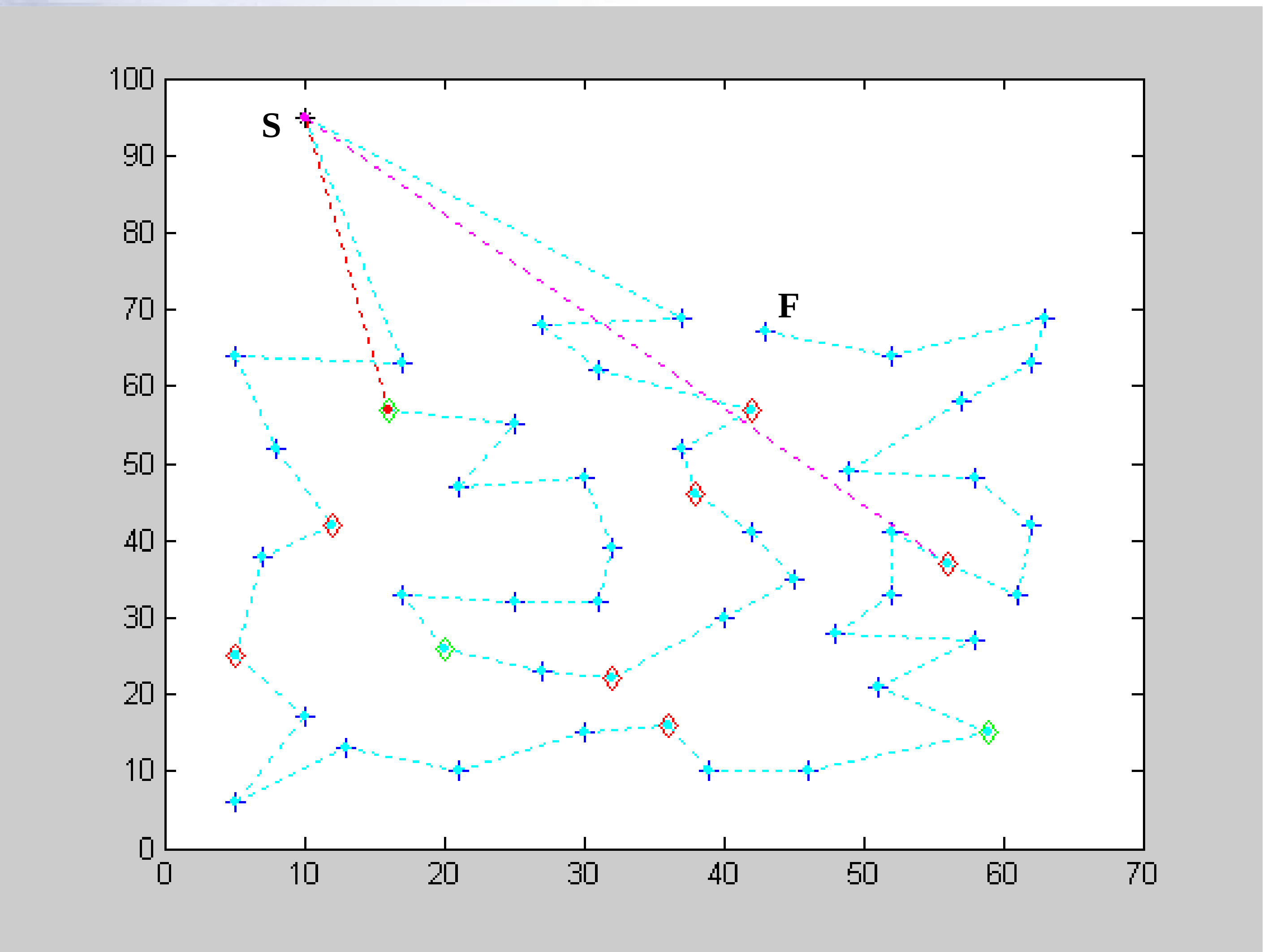
First Mine Encounter



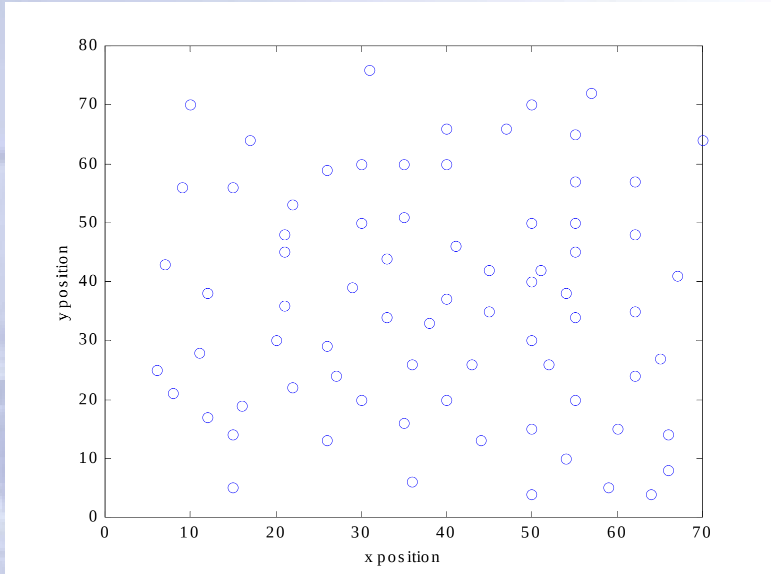
Reload Decision



Overall Path



Optimal Prosecution Sequence



Objective:

Develop Algorithms for the Optimum Prosecution Sequence of Mine-Like Contacts

Payoff:

- Improved Mission Performance
- Improved Asset Allocation

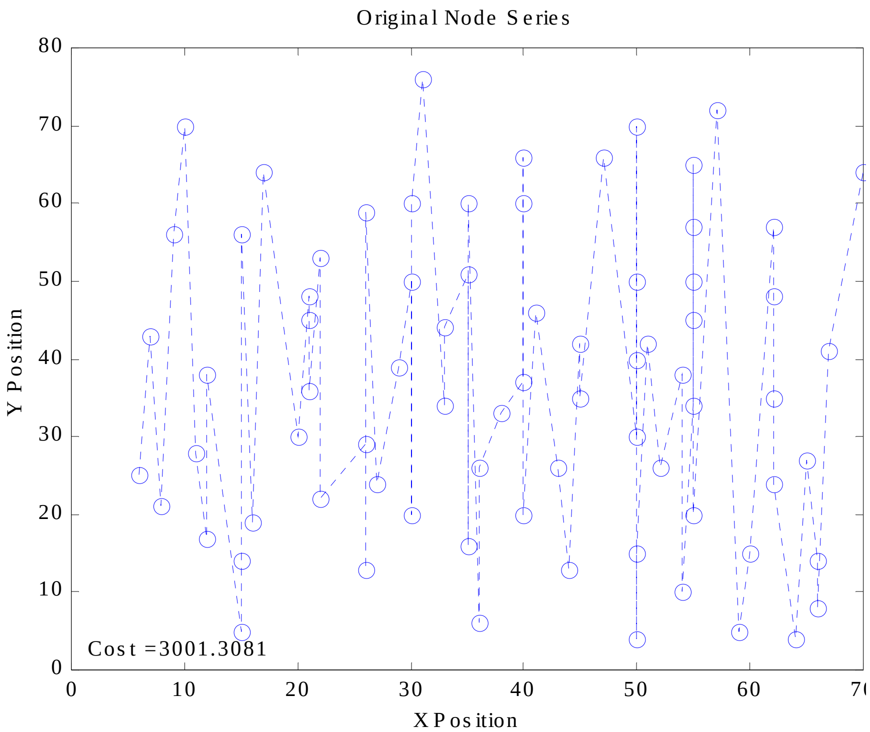
Technical Issues:

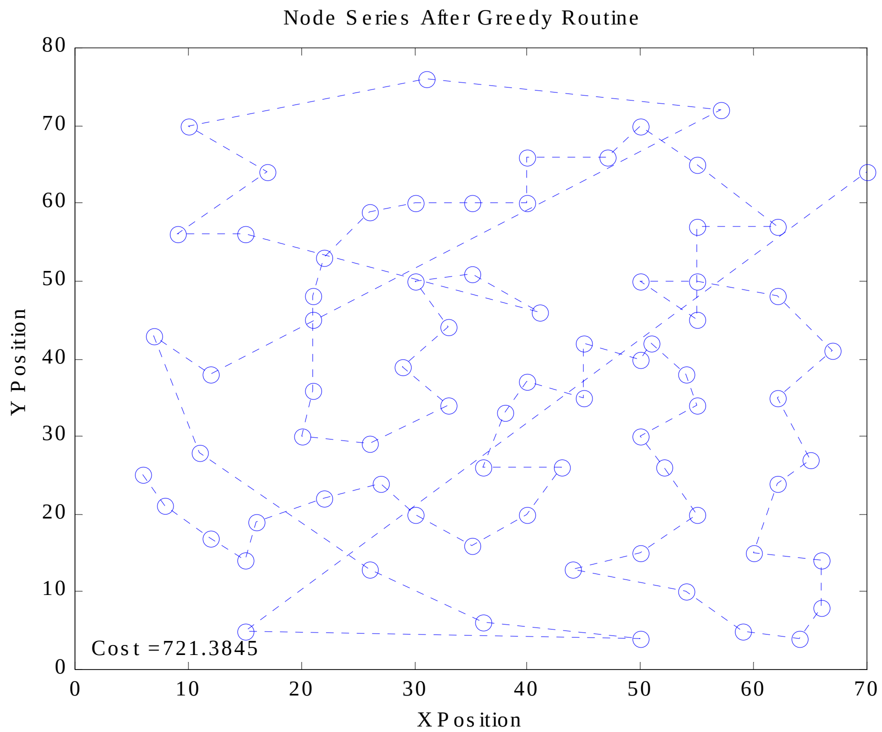
- Single vs. Multiple
  - platforms
  - prosecution devices
  - sorties
  - areas
- Number of contacts (N! Problem)
- Non-uniform contact weighting

Results to Date:

- Exhaustive search yields optimum for small no. of mines
- Sub-optimum solution developed for S/S/S/S and is in MEDAL
- Multi-Platform (M/S/S/S) solution partially developed

Hybrid Results, 75 Nodes





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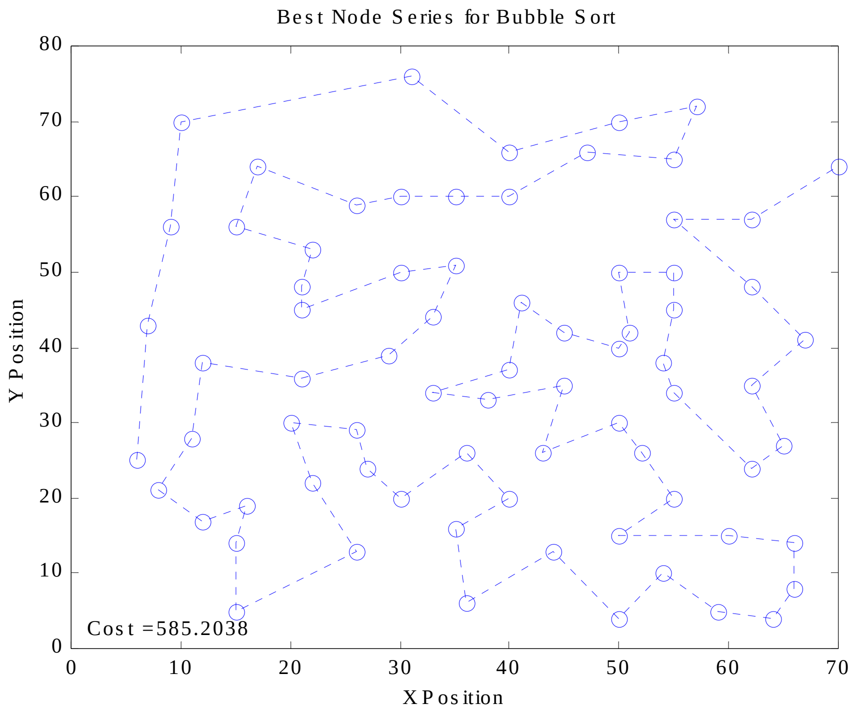

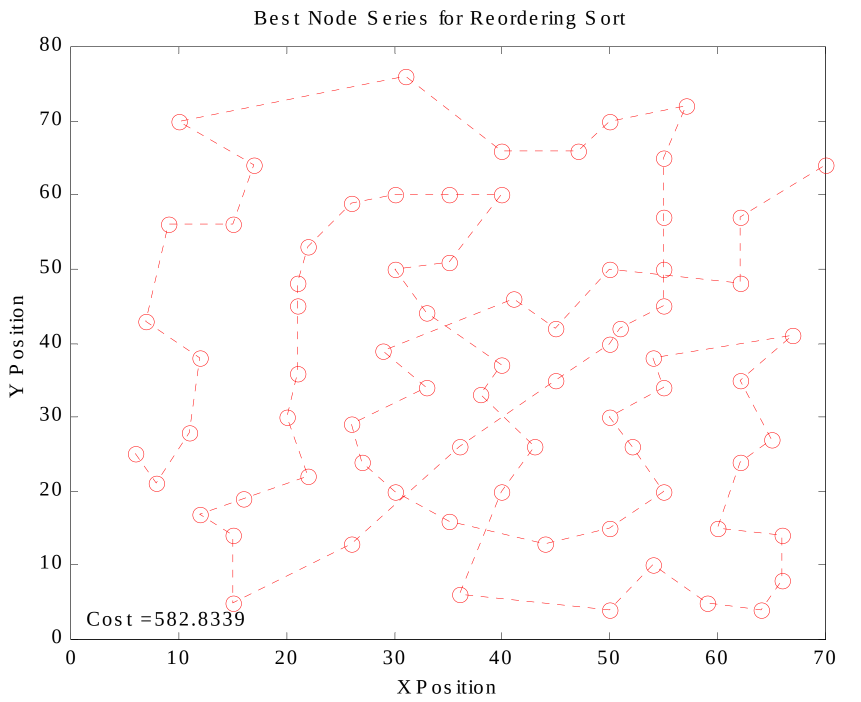

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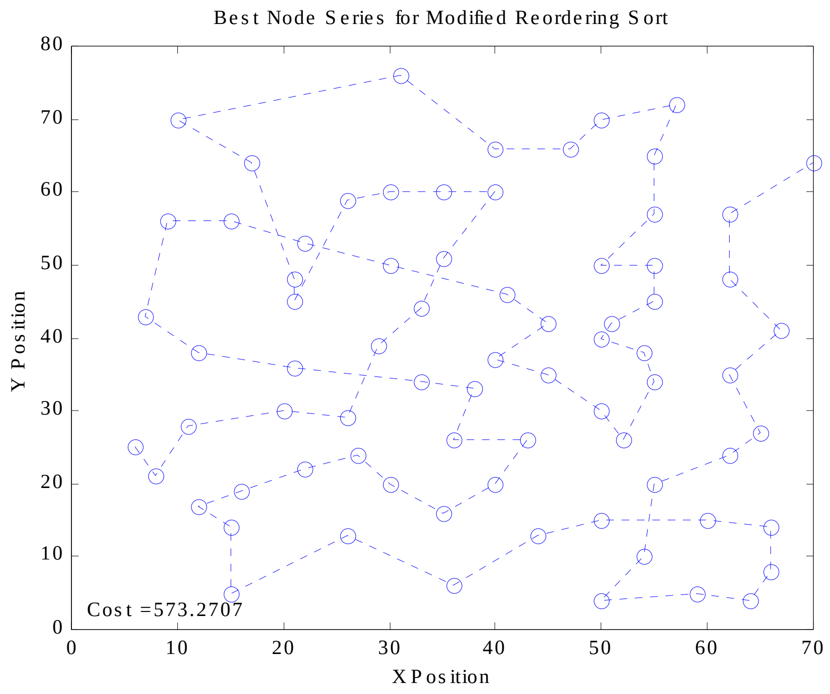
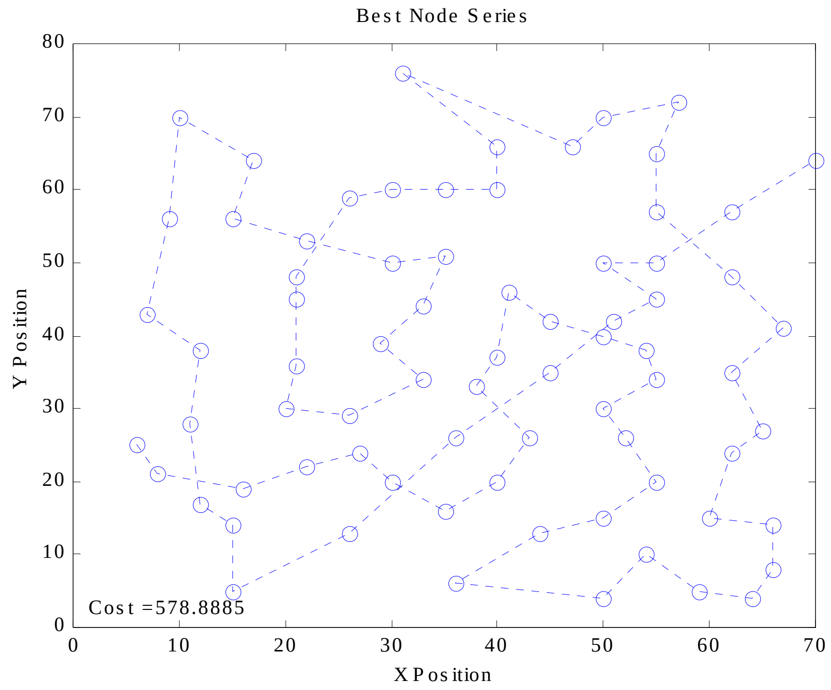
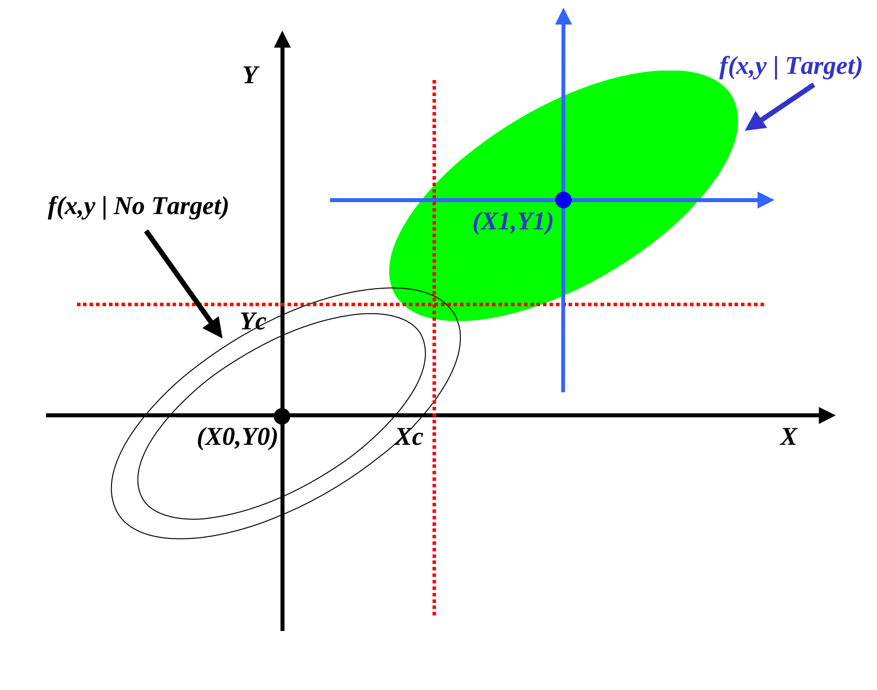


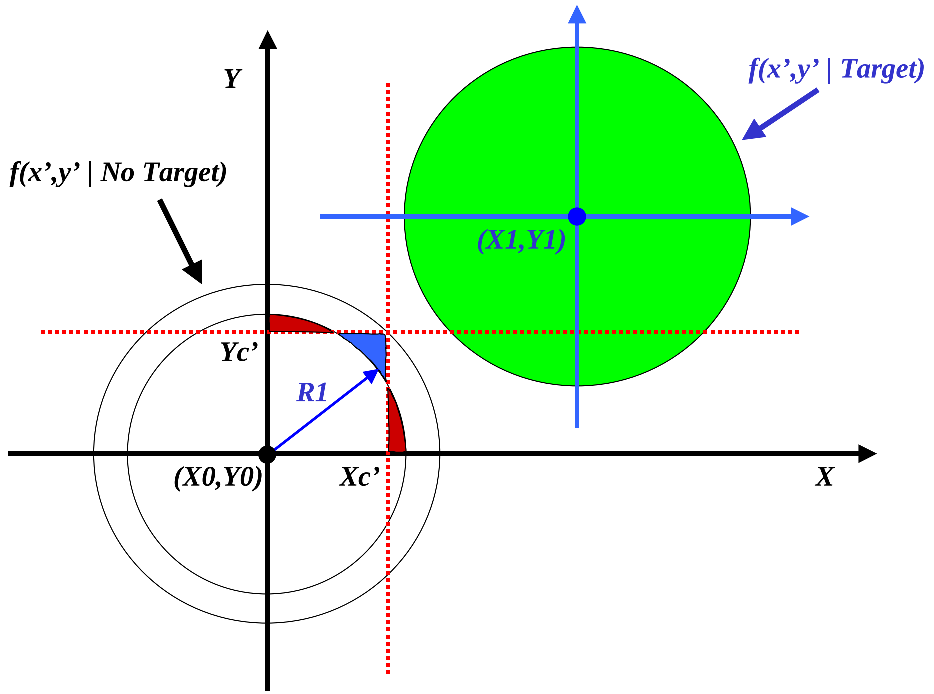


Hybrid Results Summary, 75 Nodes	
Method	Cost
Original	3,001.31
Greedy Routine	721.38
Bubble Sort	585.20
Re-Ordering Sort	582.83
Modified Re-Ordering	578.89

Joint Decision Regions

Hybrid decision region to reflect the independent nature of separate classifiers while accommodating subtle dependencies





Common Theme - Optimized Decision-Making

- Decisions designed to maximize the probability of 'success' (i.e. shorter mission time, improved Pd,…)
- Small but consistent use of better choices gives easily obtainable performance boost
- Inexpensive
- Applies tried & true methods – playing the odds to improve performance
- Measurable performance increase with no measurable cost increase

Application to Current Navy Programs

Mission Pre-Planning – Optimize the initial setup

- **Asset allocation - LCS**
- **Mission package selection - LCS**
- **Sensor selection – AUVs (BPAUV, BOSS, RMS)**

Real-Time Decision Making – Adaptive re-planning

- **Reloading strategies – Crawlers**
- **Mine avoidance – LCS, AUVs**
- **Asset trajectories – LCS, Crawlers, AUVs**

Post Mission Data Mining – Extract more information

- **Joint performance of sensors, assets, mission packages – LCS, Crawlers, AUVs**

Conclusions

- Numerous tried & true techniques exist for Mine Warfare Optimal Decision Making

Optimization Techniques For Mine Warfare Decision Making

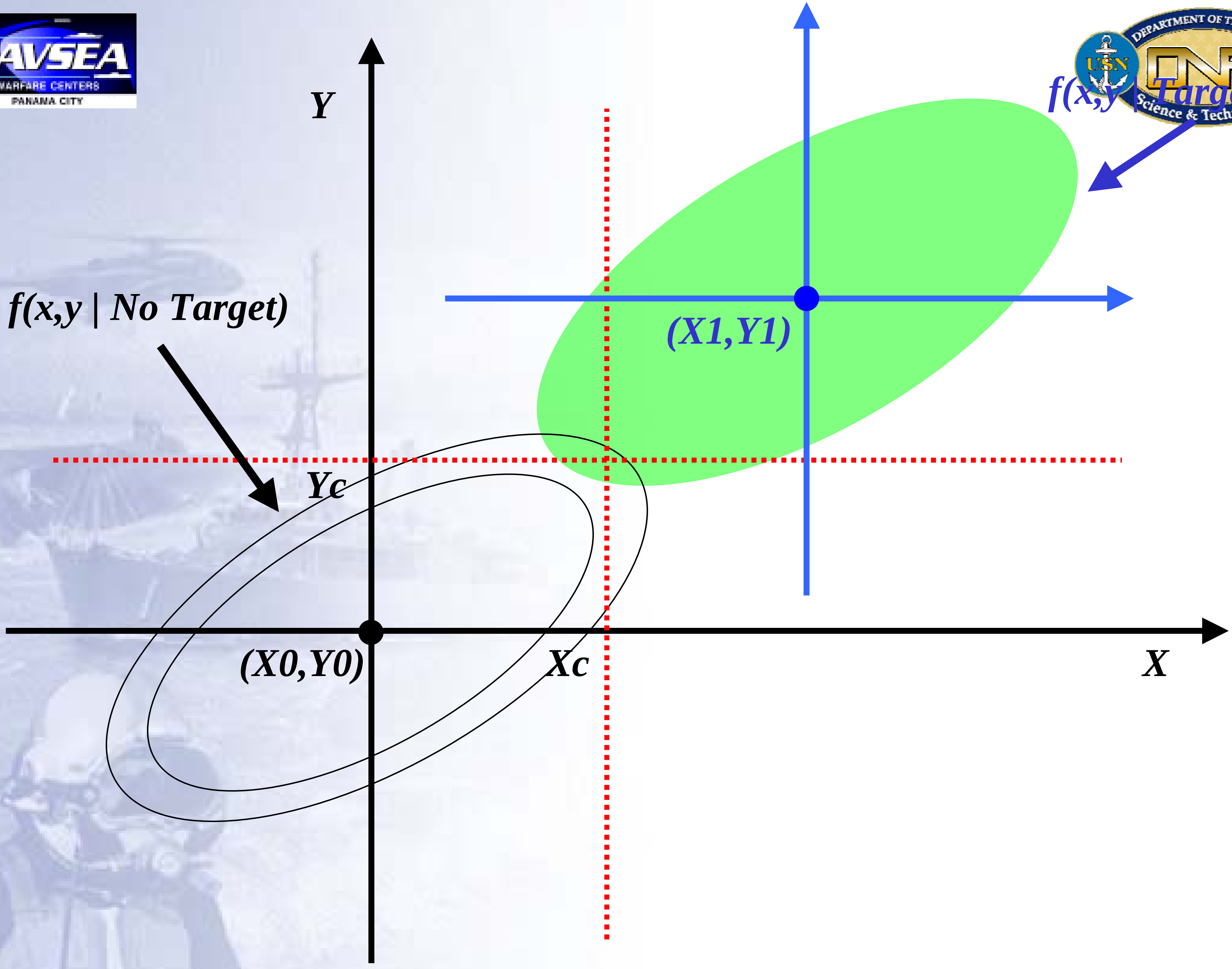
- Search Tree Algorithms
- Dynamic Programming
- Markov Process Modeling
- Monte Carlo Simulations
- Incremental Optimization
- Combinatorial Optimization
- Bayesian Strategy Analysis
- Multidimensional/ Multivariate Probabilistic Modeling

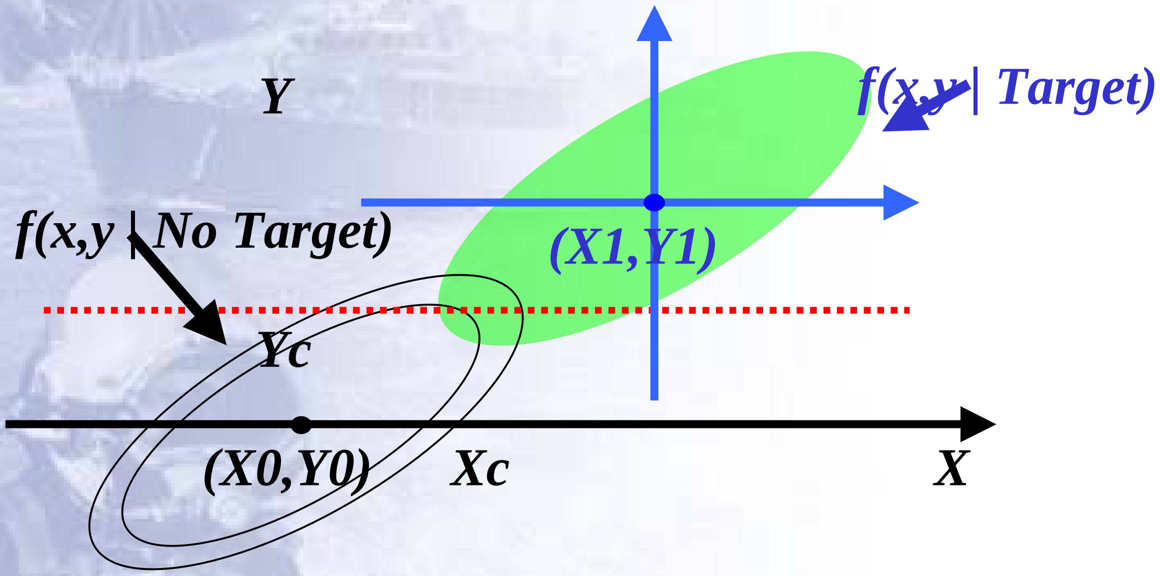
Conclusions

• The current planar analysis approach greatly over simplifies the analysis problem and eliminates optimization opportunities. This over simplification is a fundamental modeling flaw; expanding the dimensionality of the analysis provides enormous opportunity for improved performance.

• Applying these methods yields easily obtainable performance increases with no measurable cost increase.

• Much of the required sensor performance data may not currently be available.


Y
f(x,y | No Target)
f(x,y | Target)
(X1,Y1)
Yc
(X0,Y0)
Xc
X


f(x,y | Target)
Y
f(x,y | No Target)
(X1,Y1)
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(X0,Y0)
Xc
X

Conclusions

Mission Pre-Planning – Optimize the initial setup

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Post Mission Data Mining – Extract more information

- Joint performance of sensors,
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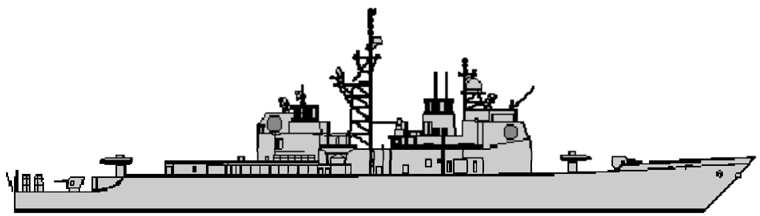
Conclusions

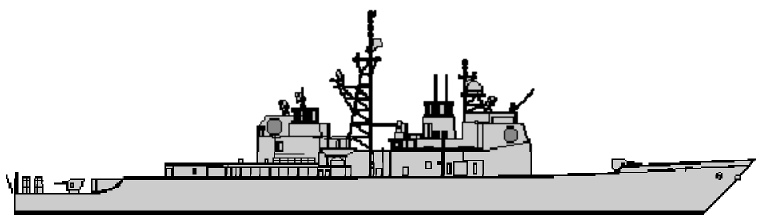
1. Asset Allocation

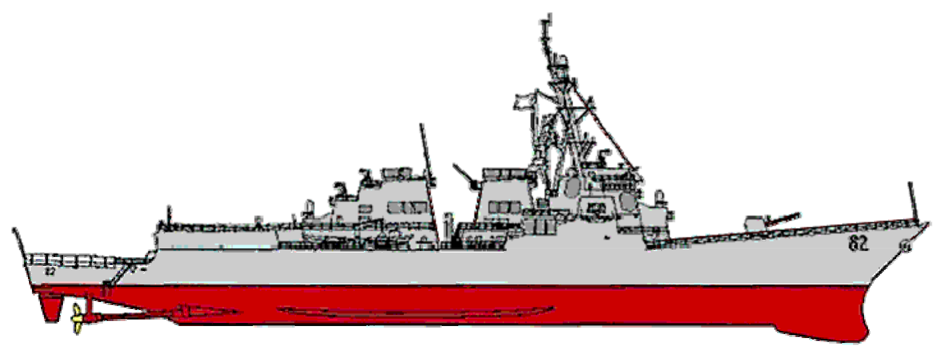
2. Multi-Dimensional Tactical Analysis

3. Optimization

4. Minimum Risk Mine Avoidance



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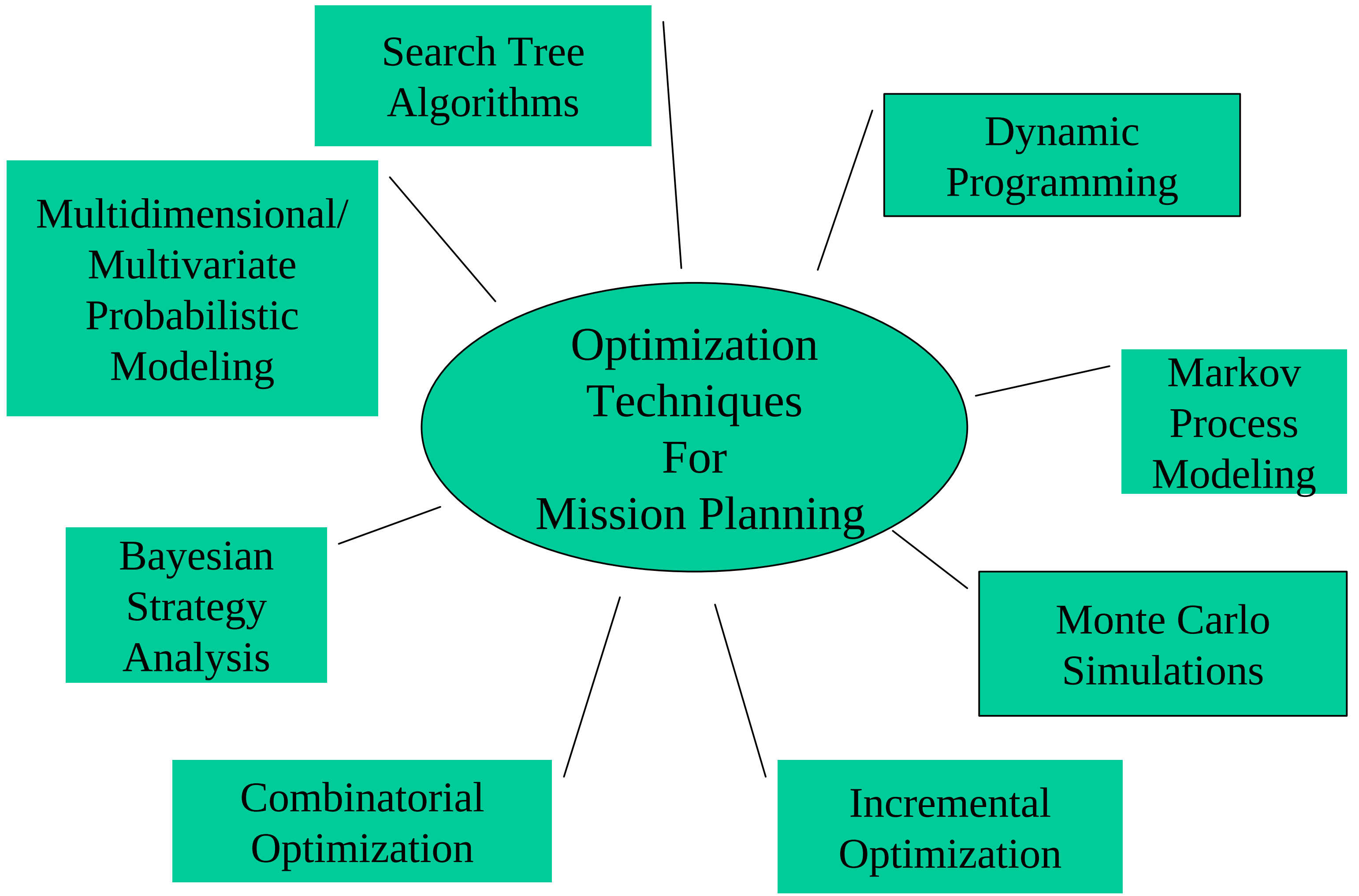
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